

28 December 1966

Materiel Test Procedure 3-2-821
Aberdeen Proving Ground

U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

BALLISTIC DATA FOR BOOSTED PROJECTILES

1. OBJECTIVE

— The objective of the procedures outlined in this MTP is to provide a means of obtaining trajectory data during the boosted portion of flight, to determine the space coordinates and time of burnout, and to determine the initial velocity components of the ballistic (free flight) trajectory of boosted projectiles.

2. BACKGROUND

A boosted projectile is an artillery missile subject to thrust forces over some portion of its trajectory, usually an early portion. Motion of the projectile during boosted flight is not as readily predicted as during free ballistic flight when only gravitational and aerodynamic forces are acting. Exacting tests may require extensive measurements during the boosted portion of the trajectory and over critical portions of the free (ballistic) flight trajectory. Less exacting tests may require measurements for only general information, specific events on the trajectory, or for assessment of only certain components of motion.

For measuring trajectory points of boosted projectiles as a function of time, Doppler type radar has proven of prime value, since it provides a continuous record over extended portions of the trajectory (both boosted and ballistic portions). As an example, at Aberdeen Proving Grounds, a Hawk Weapons System Illuminator (velocimeter) has been modified to serve in this capacity. Doppler observations, which place the missile on an expanding sphere centered at the instrument, may be combined with simultaneous photographic data to obtain the desired trajectory data.

Properly used, these procedures can aid in determining the acceptability of boosted projectiles for an intended use.

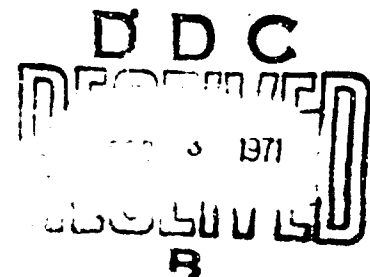
3. REQUIRED EQUIPMENT

- a. Velocimeter and Recording Van
- b. Cameras
- c. Cinethodolites and Oscillograph
- d. Electrical Sequencer
- e. Range Time Code Generator
- f. Magnetic Tape Recording System
- g. Sky Screens
- h. Meteorological Support Facility

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4. REFERENCES

- A. MTP 3-2-827, Radar Chronographs.
- B. MTP 4-2-805, Projectile Velocity, Time of Flight, and Ballistic Coefficient.
- C. MTP 4-2-821, The Doppler Velocimeter.
- D. MTP 2-2-807, Telemetry.
- E. MTP 4-2-816, Photographic Instrumentation for Trajectory Data.
- F. MTP 3-2-826, Cinetheodolites.
- G. MTP 3-2-616, Radio Frequency Radiation Hazards to Personnel.

5. SCOPE

5.1 SUMMARY

The procedures in this document outline methods for obtaining trajectory data during the boosted portion of flight, determining the space coordinates and time of burnout, and to determine the initial velocity components of boosted projectiles utilizing a Doppler velocimeter and associated instrumentation.

5.2 LIMITATIONS

The procedures in this MTP are limited to tests of boosted projectiles. They intentionally were made general to provide coverage for various artillery projectiles. Certain projectiles may not present a useable radar target. Projectiles with hemispherical, conical, finned base configurations, or having discarding parts are examples of potentially poor targets. Radar circuitry precludes tracking at velocities of less than 150 feet per second.

6. PROCEDURES

6.1 PREPARATION FOR TEST

a. Select a test site using the following criterion:

- 1) The launcher area forward of the velocimeter must be free of vibrating guy wires, metallic plates, rotating machinery, test towers, or other metallic structures.
- 2) There must be no dense vegetation or terrain rises downrange.
- 3) Aircraft must be prevented from entering the velocimeter radiation pattern area.
- 4) Direction of prevailing winds must be such that ionized gases from booster propellant and gun charges will be blown away, and will not attenuate radar waves. Discarding parts (e.g., sabot, boosters, etc.) should not be blown into the velocimeter radiation pattern to present a multiple target threat and the possibility of tracking the wrong target.

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b. If possible, select test equipment having an accuracy of at least ten times that of the function to be measured.

c. Record the following information:

- 1) Prevailing meteorological conditions prior to start as well as during conduct of the tests.
- 2) Nomenclature, serial number(s), and the manufacturer's name of the test item(s).
- 3) Last date calibrated of the test equipment selected for the tests.

d. Assure that all test personnel are familiar with the required technical and operational characteristics of the item under test, such as stipulated in Qualitative Material Requirements (QMR), Small Development Requirements (SDR), and Technical Characteristics (TC).

e. Review all instructional material issued with the test item by the manufacturer, contractor, or government, as well as reports of previous similar tests conducted on the same type of test items, and familiarize all test personnel with the contents of such documents. These documents shall be kept readily available for reference.

f. Prepare record forms for systematic entry of data, chronology of test, and analysis in final evaluation.

g. Prepare adequate safety precautions to provide safety for personnel and equipment, and ensure that all safety SOP's are observed throughout the test.

NOTE: A radiation hazard exists when the velocimeter is aimed directly at personnel (See MTP 3-2-616). At low elevation firings, particularly, the launch area must be clear of personnel when the velocimeter radiating power is applied.

6.2 TEST CONDUCT

a. Emplace the firing weapon in a precisely surveyed position at the test site. Record weapon position coordinates.

b. Install a Hawk velocimeter (and its recording van) adjacent to the weapon (in a preselected precisely surveyed position) in such a manner that the velocimeter and its van are protected from blast and shock. The velocimeter should be positioned to acquire the projectile as soon as possible within its tracking limitations (24 degrees/second). Record the velocimeter position coordinates.

c. Install fixed detecting cameras or sky screens positioned (one on each side of the launcher, in precisely surveyed positions) to detect the projectile after velocimeter acquisition (see Figure A-1). Record camera or sky screen position coordinates and angular orientation.

d. Install boresight cameras or cinetheodolites adjacent to and aligned with the weapon bore axis (Figure A-1) in presurveyed positions and in such a manner that they are protected from blast and shock. Record camera or cinetheodolite position coordinates and orientation.

NOTE: If cinetheodolites are employed, connect an oscillograph to the cinetheodolite and the range instrumentation system to correlate frame time.

e. Connect a range time code generator to all camera stations and the velocimeter recording system. Connect an electrical sequencer between the cameras and the weapon.

f. Apply equipment power and calibrate the velocimeter recording system as a unit.

g. Load the firing weapon, perform appropriate safety checks, and fire.

h. Acquire the projectile with the velocimeter and track until the impact point is reached or the projectile exceeds maximum range. Record data until the end of flight of the projectile.

i. Repeat steps (f), (g), and (h) above, as necessary to obtain the required data.

6.3 TEST DATA

6.3.1 Preparation for Test

Data to be recorded prior to testing will include but not be limited to:

- a. Nomenclature, serial number(s), and manufacturer's name(s) of the test item(s) and all components and accessories.
- b. Last date calibrated of the test equipment selected for the tests.
- c. Expected muzzle velocity.
- d. Expected range.
- e. Expected ignition time
- f. Expected burnout time
- g. Firing elevation
- h. Prevailing meteorological conditions prior to start, as well as during conduct, of the tests, to include:

- 1) Temperature
- 2) Humidity, relative or absolute
- 3) Temperature gradient
- 4) Atmospheric pressure
- 5) Precipitation
- 6) Wind speed and direction
- 7) Pibal data
- 8) Frequency of readings
- 9) Source of data

6.3.2 Test Conduct

Data to be recorded in addition to required ballistic data for each specific test shall include:

- a. Weapon position coordinates.
- b. Velocimeter position coordinates.
- c. Detecting camera or sky screen coordinates and angular orientation.
- d. Boresight camera or cinetheodolite coordinates and orientation.
- e. Photographs or motion pictures (black and white or color), sketches, diagrams, maps, charts, graphs, or other pictorial or graphic presentations which would support test results or conclusions.
- f. An engineering logbook containing, in chronological order, pertinent remarks and observations which would aid in a subsequent analysis of test data. This information may consist of temperature, humidity, and other appropriate data, or other description of equipment or components, and functions and deficiencies.

6.4 DATA REDUCTION AND PRESENTATION

The range time code recorded on the velocimeter magnetic tape and the photographic films make it possible to correlate observations from the cameras with the radar records. The velocimeter record obtained in the field is processed through a series of operations that will provide a digital representation of the Doppler frequency as a function of time. This frequency, hence the radial velocity, is then in a form acceptable to a high-speed digital computer. Camera coverage provides projectile position coordinates at a time after the velocimeter has begun to track the projectile. By combining these data with the radar information, computations will provide the following:

- a. Continuous vector or tangential velocity versus time along the entire trajectory or for the limitations of the system. This information is usually presented in graphical form.
- b. Position coordinates as a function of time, usually presented in tabular form.

All test data shall be properly marked for identification and correlation to the test item in accordance with paragraph 6.3 as a minimum.

A written report shall accompany all test data and shall consist of conclusions and recommendations drawn from test results. The test engineer's opinion, concerning the success or failure of any of the functions evaluated, shall be included.

Equipment evaluation usually will be limited to comparing the actual test results to the equipment specifications and the requirements as imposed by the intended usage. The results may also be compared to data gathered from previous tests of similar equipment.

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GLOSSARY

1. Burnout Time (B.T.) - the elapsed time from firing to the point in time when the powered flight ceases. It is also the time that the ballistic (free flight) trajectory starts.
2. Burnout Velocity (B.V.) - the velocity of the projectile at burnout time. This velocity is a vector and should be expressed in terms of its three components.
3. Burnout Position (B.P.) - that position in space occupied by the projectile at burnout time.

BALLISTIC DATA FOR BOOSTED PROJECTILES

APPENDIX A

1. GENERAL

Boosted projectile tests are usually conducted to verify the adequacy of design and materials selection and to establish performance characteristics such as reliability, accuracy, and terminal effects. The acquiring of accurate ballistic data from the firing of such projectiles greatly aids in evaluating the performance of the projectiles from the standpoint of design considerations.

The following paragraphs describe some of the instrumentation generally used in boosted projectile firing tests and some of the factors involved in obtaining ballistic data.

2. INSTRUMENTATION

2.1 HAWK VELOCIMETER

The Hawk velocimeter is a continuous wave radar which has been modified to detect Doppler frequencies corresponding to projectile velocities up to 10,000 feet per second. It can lock-on and track the projectile to a distance of 40,000 feet, and it gives continuous velocity-time data. A magnetic tape recording system in a portable van is used to record the various velocimeter outputs as a function of time. The velocimeter measures the difference between transmitted and received frequency, which is converted in the computer to radial velocities, which is the velocity component along the line joining the velocimeter and the projectile. The computer then calculates tangential velocities from the radial velocity data in conjunction with certain photographic data. The Hawk velocimeter should be positioned as close as possible adjacent to the weapon along the line of fire. It must be shielded, as in a barricade, for protection against shock waves and flying debris that might temporarily or permanently disable it. The Hawk velocimeter has the following performance characteristics:

Velocity measuring range	150 to 10,000 fps
Maximum tracking range	40,000 feet(dependant upon diameter and base shape)
Antenna beam width	32.0 mil
Maximum tracking rate (slew)	24 degrees/second

2.2 CAMERAS

The selection and deployment of photographic instrumentation depends upon the test requirements and the anticipated performance of the test item. Fixed cameras having a framing rate of 100 frames per second or greater should be used to observe the tipoff of the projectile, the initial yaw characteristics, and the direction of motion as the projectile leaves the weapon.

In general, determination of the initial velocity components of the ballistic trajectory (velocity at burnout) results from accurate tracking of the projectile for some time after burnout. This may be accomplished by means of cameras, or by the use of camera and velocimeter data combined. Because some boosted ammunition is under thrust for a considerable length of time, the projectile may be too high to photograph satisfactorily at burnout. In such cases it may be necessary to fire at reduced quadrant elevations to obtain the data. The camera framing rate and field of view are selected so that a sufficient number of points can be determined with respect to time.

2.3 CINETHEODOLITES

Cinetheodolites may be employed in tests where portions of the trajectory cannot be recorded by fixed cameras. The frame time is correlated with the range instrumentation time by recording both on an oscillograph.

2.4 RANGE TIME CODE GENERATOR

The range time code generator provides a single time code to all camera stations and the velocimeter recording system.

2.5 ELECTRICAL SEQUENCER

The electrical sequencer coordinates the running of the cameras with the firing of the weapon.

2.6 VELOCIMETER RECORDING SYSTEM

A magnetic tape recording system records the various velocimeter outputs as a function of time from the initial start pulse to completion of the test. The range time code is also recorded in order to correlate the velocimeter data with the photographic data.

3. DATA ACQUISITION

The complexity and costs of the test vary greatly depending upon the amount of data to be gathered; each test plan must therefore be carefully analyzed to assure a proper choice of instrumentation. The following specific information is required:

- a. Expected muzzle velocity
- b. Expected range
- c. Expected ignition time
- d. Expected burnout time
- e. Firing elevation

3.1 CONTINUOUS VELOCITY VERSUS TIME AND POSITION DATA (Figure A-1)

The complete test setup provides ballistic data of high accuracy.

Assume that the information desired of a boosted projectile is continuous velocity versus time and position data on the ascending portion of the trajec-

tory. Maximum velocity would be assumed at burnout. The minimum instrumentation required would be:

- a. Hawk velocimeter with recording van located adjacent to the weapon and protected from blast and shock.
- b. Fixed detecting cameras or sky screens positioned (one on each side of the launcher) to detect the projectile after velocimeter acquisition (Reference 4-B).
- c. Boresight cameras or cinetheodolites placed adjacent to and aligned with the weapon bore axis and protected from blast and shock (Reference 4-F).
- d. Range time coder and sequencer.

The velocimeter should be positioned to acquire the projectile as soon as possible within its limitations (24 degrees/second). The data recorded, after proper programing, will provide continuous velocity-time results. Triangulation between the boresight cameras and detecting cameras or sky screens (with a common time provided by the range time coder) gives an accurate position for some initial point on the trajectory. (The use of two or more fixed cameras and boresight cameras provides a margin of assurance in the event of camera failure). Correlation is established between this initial point and the velocimeter data. Starting from the space coordinates of this initial point, velocity integration provides space position data along the trajectory. It is emphasized that the velocimeter, cameras, and sky screens must be precisely surveyed into preselected positions on a rectangular grid coordinate system. They should be mounted so that no change in their orientation occurs during the test. The weapon must also be precisely surveyed and any position changes between rounds recorded or corrected.

3.2 APPROXIMATE TRAJECTORY DATA USING VELOCIMETER ONLY (Figure A-2)

Certain approximate trajectory data may be obtained solely from the Doppler record. For example, early tests of new items seeking only general confirmation of design parameters may require little more than plots of radial velocity versus time along the trajectory. The "radial velocity" is, of course, the velocity of the projectile relative to the radar antenna and is proportional to the Doppler frequency that is provided as a function of time by the Doppler record. As the angle between the trajectory and the line along which the antenna views the projectile approaches zero, the radial velocity approaches the tangential velocity of the projectile. When radial velocity data alone are considered acceptable, reasonable assurance should be obtained that the angle mentioned above is sufficiently small in the region of greatest interest on the trajectory. Each test condition should be studied for assurance that the data will be adequate both as to type of trajectory data and as to accuracy. This implies prediction of the trajectory prior to the test and the consequent placement of the velocimeter so that the desired geometry is satisfied within the limits of the angular tracking rate of the antenna. In addition, it is necessary to correlate trajectory times with the radial velocity data. The data thus obtained may readily convey information on such matters as uniformity of burning, thrust duration, and general conformation of flight patterns to predicted trends and levels.

3.3 TANGENTIAL VELOCITY THROUGH FURTHER PROCESSING OF DATA

When certain initial conditions are known, and when projectile flight conforms reasonably to certain assigned restrictions on the trajectory to be derived from the Doppler record, quite close approximations may be made to the actual trajectory over limited times of flight by further processing of the radial velocities. The initial conditions are satisfied when an assignment can be made of a mean vertical plane to the trajectory, when the coordinates of a point on the trajectory are known relative to the Doppler antenna shortly before or after the start of the Doppler record, when the direction of the velocity vector at this point is known, and when no thrust discontinuity exists between this point and the delayed start of the Doppler record. The restriction imposed by the computing procedures on the derived trajectory constrains all accelerating forces, other than the component of gravity, to act along the trajectory.

It is pointed out that the effect of yawing motions of the projectile under thrust and the effect of wind components transverse to the trajectory are incompatible with the assigned restraint on the trajectory. Furthermore, this restraint precludes measurement of acceleration components normal to the trajectory. Assignment of maximum trajectory length over which the data may be characterized by a specified accuracy is conjectural.

When it is anticipated that the initial point on the trajectory may precede the start of the Doppler record and when, in this case, it is additionally expected that the projectile acceleration will depart appreciably from linearity with time, it is desirable to provide instrumentation for the measurement of both magnitude and direction of the velocity vector at this point.

3.4 APPROXIMATE BURNOUT TIME, VELOCITY, AND PROJECTILE POSITION

The intermediate test setup provides less accurate data at considerably less expense than the complete test setup. It may be used in the determination of approximate burnout time, velocity, and projectile position. This test setup is based on the assumption that the projectile will travel in a plane and that no force, other than a component of gravity, acts normal to the trajectory. When the initial point on the Doppler trajectory is to be determined by cameras, the instrumentation consists of fixed cameras that photograph the earliest portion of the trajectory. The cameras are arranged (one on each side of the launcher) to permit triangulation procedures for establishing the immediate post-launch trajectory (Reference 4-E). As in the complete test setup, a Doppler velocimeter recording radial velocity functions simultaneously with the cameras, all being referred to a common timing system. Data reduction consists of solving simplified equations of motion by use of the radial velocity. Departure of the resulting trajectory from the true trajectory may be expected to increase with time from the initial point.

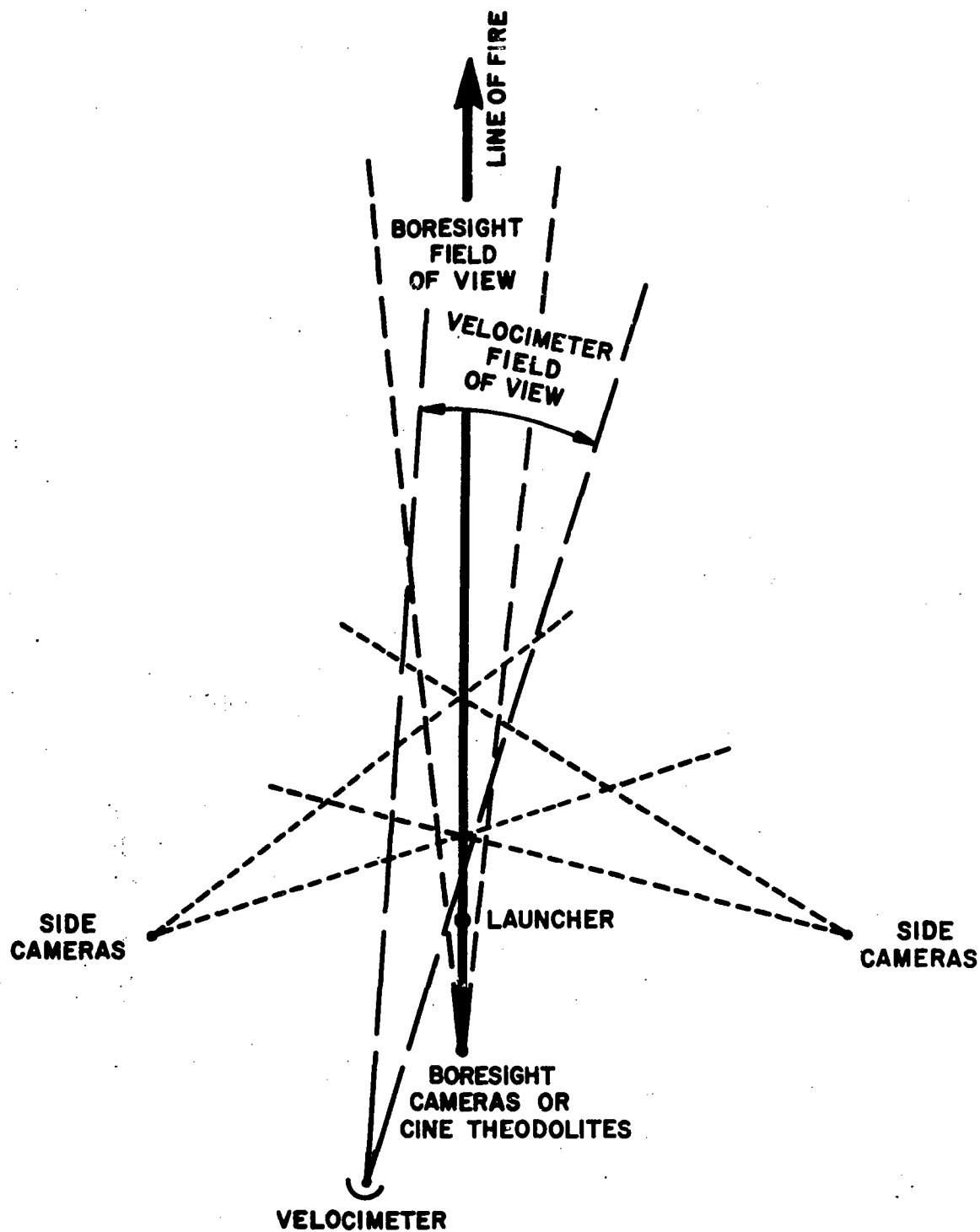


FIG. A-1 FIRINGS FOR POSITION VERSUS TIME

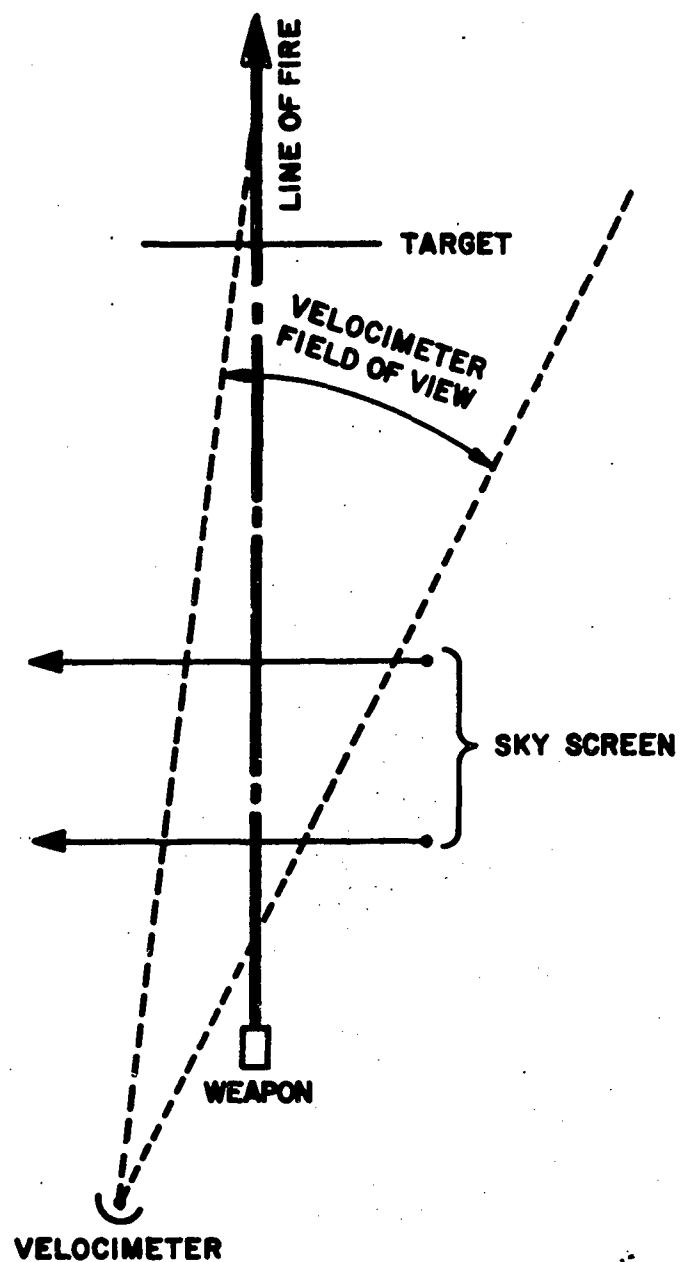


FIG. A-2 VELOCIMETER SETUP FOR RESISTANCE FIRING